Multiple scattering and absorption of solar radiation in the presence of three-dimensional cloud fields

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4D CLOUDS BMBF/AFO2000

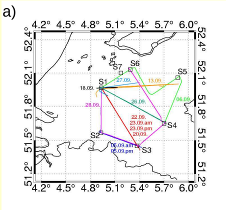
1.Introduction

In the framework of 4DCLOUDS the Baltex Bridge campaign (BBC) were conducted. During BBC FUB's Cessna served as a platform for a number of remote sensing instruments, among them *casi* and FUBISS, both measuring nadir radiances. Our scientific focus aims on the effect of spatial cloud heterogeneities on radiative transfer (RT) and remote sensing of cloud properties. Usually the horizontal and vertical distribution of cloud properties is neglected, if input fields for radiative transfer simulations, which form the basis for many retrievals of cloud properties, are generated. This may give reason for systematic and random discrepancies. We investigate the effect of absorption, surface albedo, and two layer clouds on cloud radiative smoothing by applying power spectra (PS) analysis to measurements of nadir radiances and verify the results using artificial cloud generators, Monte Carlo models, and microphysical models.

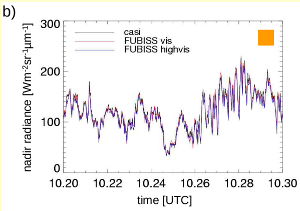
2. Measurements

a) Summary of flight tracks, 59 flights in total, max. flight level 3 km.

a)



b)



b) Time series comparison at 753 nm (2001 09 22).

3. Approach

Observations

- Cases have been defined where the leg length> 40km, cloud fraction ≈1, no altostratus, no cirrus were found. 5 flight legs meet the criteria.
- Utilise *casi*`s nadir radiance at 620 nm (two layer clouds).
- Utilise FUBISS`s nadir radiance (absorption of water vapour, 890-950 nm; surface albedo at; red edge, 660-780 nm).

RT simulations

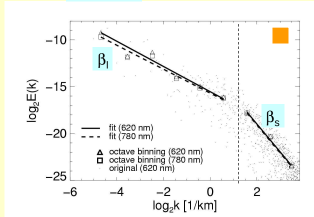
- Artificial cloud fields from Venema *et al.,* 2005.
- Microphysical model from Schüller *et al.,* 2003.
- Monte Carlo model with local estimates.
- Equivalence theorem after Irvine, 1964:

$$R^A = R^W \int pdf(l) \exp(-\sigma_a l)\, dl$$

with σ_a: volume absorption coefficient, R^A (R^W) reflectance in a(n) absorbing (window) channel, pdf(l): normalised photon path length distribution.

Power spectra E(k) of nadir radiances are analysed to determine slopes and to identify scale breaks indicated by a changing slope β in $E(k) \sim k^{-\beta}$.

a) Exemplary PS analysis of nadir reflectance from FUBISS (2001 09 10).

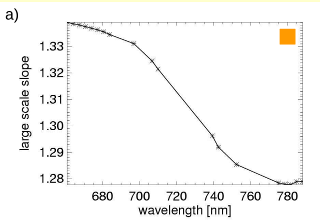


a) Original PS of reflectances at 620 nm (dots). Other symbols give the octave binned PS.

In this way the effect on radiative smoothing in observations is quantified and verified with the same analysis applied to RT simulations.

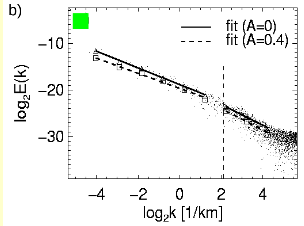
4.a Radiative Smoothing: Surface albedo

a)



a) Surface albedo effect (2001 09 20), see also Fig. a in 3. Approach.

b)



b) Surface albedo effect in RT simulations. We have:

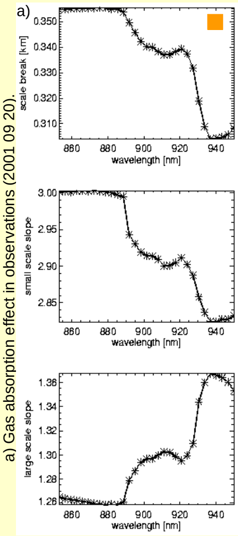
$\beta_l(A=0) = 1.79 \pm 0.03$
$\beta_l(A=0.4) = 1.62 \pm 0.05$

- We extend the term "radiative smoothing" to large scale and small scale (see 4.b) cloud radiative smoothing in order to differentiate between effects on different scales.
- In both, observations and simulations an increase in large scale cloud radiative smoothing is found, in evidence of a decreased large scale slope.
- The albedo brightens optically thin cloud parts and leaves optically thick parts almost unchanged. It is expected to be effective on scales of the typical diameter of clouds, e.g. 3-5 km for marine stratocumulus.
- Differences in β_l may occur due to average surface albedos smaller than 0.4 and differences in cloud statistics.
- The effect on small scale slope and scale break is not significant.
- Uncertainties are estimated by subsetting each bin which has been defined for binning.

4.b Radiative Smoothing: Water vapour absorption

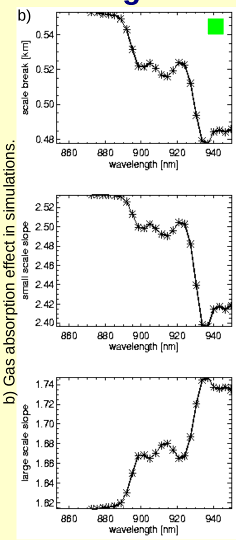
a) Gas absorption effect in observations (2001 09 20).

a)

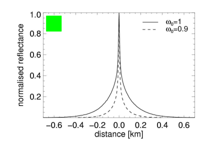


b) Gas absorption effect in simulations.

b)



- Horizontal photon transport (HPT) causes a scale break at ~300 m.
- Gas absorption prevents HPT (decrease of β_s and scale break, small scale cloud radiative smoothing) and



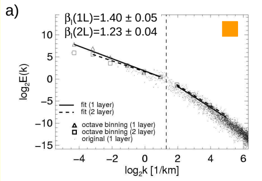
Simulation (with varying absorption intensity) is based on injection of photons at a single position.

- inhibits multiple scattering between cloud and surface (increase of β_l).
- Statistical significance is given.

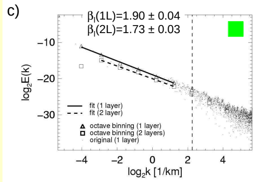
4.c Radiative smoothing: Two layer clouds

a) Two layer cloud effect in obs. (ensemble of 5 data sets).

a)



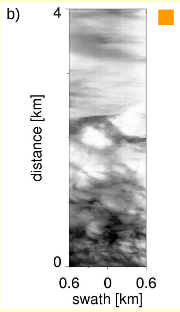
c)



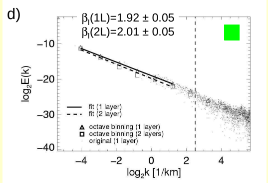
c) Two layer cloud effect in sim. (arbitrarily chosen cloud fields).

b) *Casi* image at 620 nm, showing radiative smoothing in a transition from single to two layer clouds.

b)



d)



d) Two layer cloud effect in sim. (cloud fields with minimum in $|\tau_{upper\ l.} - \tau_{lower\ l.}|$).

- Two layer clouds enhance probability for an increase of large scale cloud radiative smoothing.
- Effect depends on relative distribution of the cloud optical thickness of both layers.
- The effect on small scale slope and scale break is not significant.

5. Conclusion

We analysed the effect of gas absorption, surface albedo, and two layer clouds on cloud radiative smoothing. In order to identify these effects we applied power spectra analysis. We found a variety of effects in airborne measurements of nadir radiances, and introduced the terms large and small scale cloud radiative smoothing (as an extention of cloud radiative smoothing). Large surface albedos and two layer clouds prevent multiple scattering between surface and cloud on the one hand and lower and upper cloud layer on the other hand and therefore enhance large scale cloud radiative smoothing. Large absorption intensities inhibit HPT so that small scale cloud radiative smoothing and the scale break is reduced. In the presence of high values of surface albedo, gas absorption reverses the surface albedo effect. All results were successfully verified by a similar analysis applied to radiative transfer simulations. The investigated impacts significantly alter photon statistics and therefore satellite retrievals of atmospheric products relying on solar radiation. Future work will estimate the uncertainties of such retrieval schemes.

References / Acknowledgements

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